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PRESSURES WITH A RAILGUN

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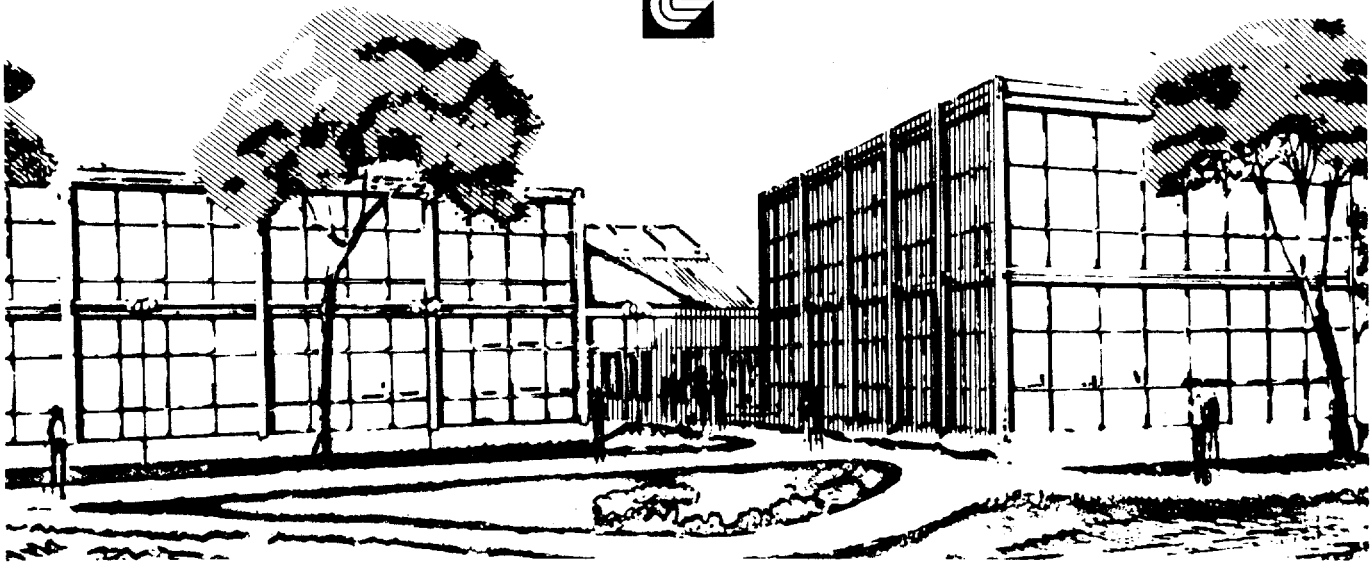

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PROSPECTS FOR GENERATING 1-10 TPa PRESSURES WITH A RAILGUN*

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Abstract

It has been demonstrated that a plasma arc can be accelerated along two current carrying parallel rails and used to accelerate a projectile [1]. We have performed an extensive analysis and found the task of using a railgun to accelerate an impactor plate to velocities of 10-40 mm/μs to be feasible with contemporary technology. This range of impact velocities would enable shock pressures of 1-10 TPa to be generated for EOS research.

Introduction

The use of shockwave techniques to obtain high pressure equation of state (EOS) and other properties has been extensive for many years. The pressures that are attainable are directly linked to the velocity attainable in a flyer plate. This velocity has been limited to about 6-7 mm/μs for both explosive and light gas gun (including 2 stage) accelerated plates. There appears to be little hope of extending the limits on these techniques. We have examined the potential performance of the electromagnetic railgun and concluded that it offers promise of easily accelerating flyer plates to velocities well in excess of 10 mm/μs.

Principle of Operation

The magnetic railgun is essentially a linear dc motor consisting of a pair of rigid parallel conductors that carry current to and from a small interconnecting moveable conductor. The connecting link functions as an armature while the parallel rails serve as a single-turn field winding (see Figure 1).

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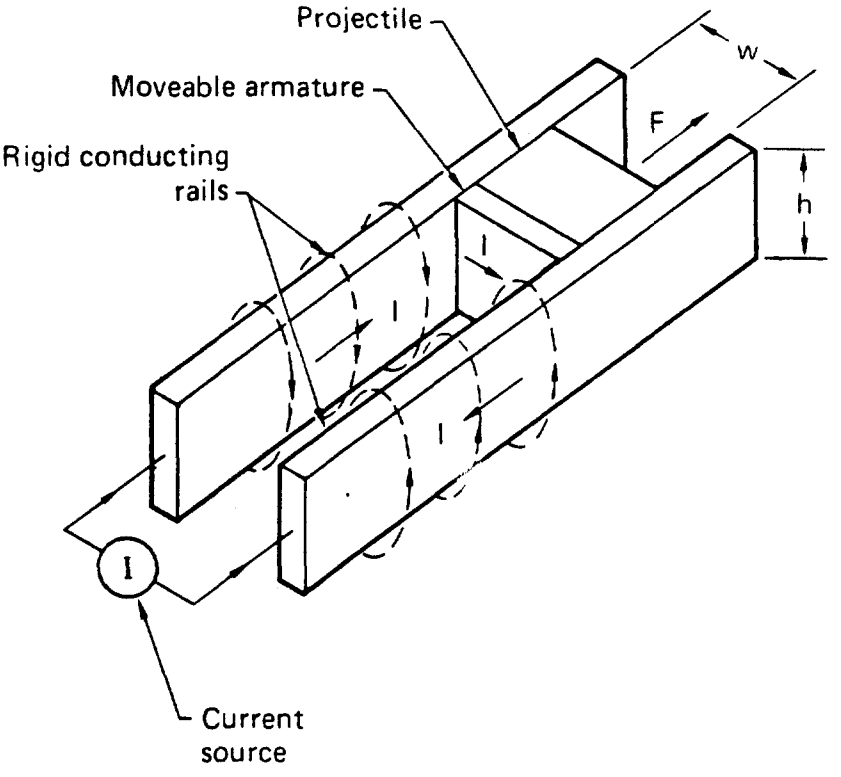

Figure 1. Railgun Accelerator

The force F on the armature is given by,

$$F = \frac{L_1 I^2}{2} ,$$

where I is the armature current, and L_1 is the inductance per unit length of the rail pair. A typical "square bore" configuration, where the rail separation w is equal to rail height h, has an L_1 equal to ~0.42 μH/m. Thus a 10^6-A current will produce 2.1 x 10^5 Newtons of thrust on the armature.

Limits of Operation

We have examined the fundamental and technical issues that are believed to control dc-railgun efficiency and performance [2]. Topics considered included resistive heating and magnetic loading of the parallel rails; stress considerations within the rail support structure; interior ballistics of the projectile, including dynamic loading and drag; and, finally, estimates of launcher performance as a function of input energy. It was found that limits result from the properties of the rail and projectile materials, interior ballistics of the projectile, and available energy.

Table 1. Summary of Anticipated Limitations

Limiting Factor	Limit		Value Used
Rail Melting (Copper)	1083 C	I/p = 43 kA/mm	16 kA/mm
Rail Yielding (Steel)	1 GPa	I/w = 75 kA/mm	75 kA/mm
Sabot Failure (Graphite composite)	1.4 GPa	I/w = 81 kA/mm	75 kA/mm
Projectile Stability	A_R = 0.5		0.5

where, p is the perimeter of the rail cross-section, and A_R is the aspect ratio of the projectile.

Simulation of Railgun Performance

We have simulated the railgun operation with a computer code. The code accurately reproduced the performance of the Australian National University [1] railgun and is used here to predict operation at velocities >10 mm/μs.

The railgun simulation code was used with the limitations described above to determine the expected performance of a railgun using a sabot to launch a flyer plate for impacting an EOS target. Table 2 below lists representative results for 25- and 12.5-mm diameter, 1.5mm thick tantalum flyer plates, launched by 30- and 20-mm square bore, self-supporting sabots. Figures 2 and 3 show the launch velocity vs initial stored energy for the 25- and 15-mm diameter flyers, respectively.

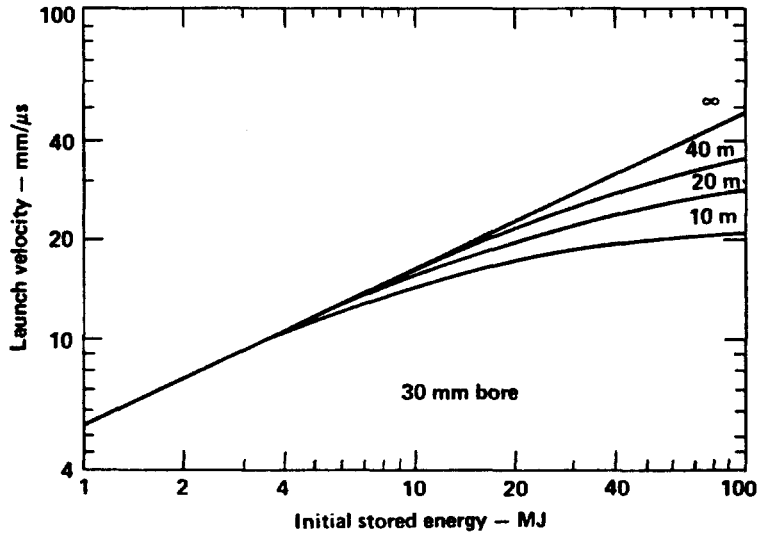

Figure 2. Launch velocity vs stored electrical energy for a 25 mm diameter by 1.5 mm thick tantalum flyer and sabot.

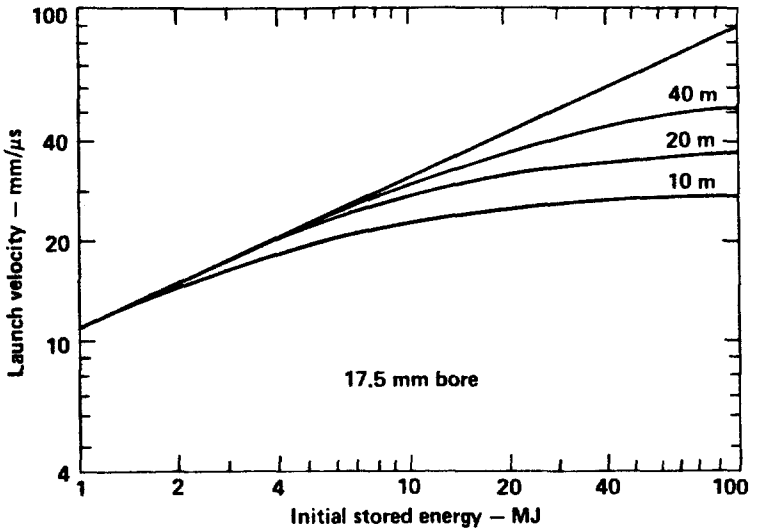

Figure 3. Launch velocity vs stored electrical energy for a 12.5 mm diameter by 1.5 mm thick tantalum flyer and sabot.

Table 2. Calculated Railgun Performance

Initial Stored Electrical Energy		20MJ		50MJ	
Velocity (Ta dia.)		v(25mm)	v(12.5mm)	v(25mm)	v(12.5mm)
Launcher Length	10m	17 mm/μs	25 mm/μs	19.5mm/μs	26.5mm/μs
	20m	20 mm/μs	31.5mm/μs	25 mm/μs	36 mm/μs
	40m	21.5mm/μs	37.5mm/μs	29.5mm/μs	46 mm/μs

Conclusion

We conclude that a 50 MJ stored electrical energy source (inductor, capacitor, etc.), together with a 20m railgun barrel can be expected to launch a 12.5 mm diameter, sabot-supported tantalum disc to 36 mm/μs. A similar result should be achievable with about half of the initial stored energy and twice the barrel length. The flyer plate would generate an extropolated, single shock pressure of ~10 TPa upon impacting a tantalum target. Reflected and multiple shock as well as magnetic compression [3] techniques are also suitable for use with a railgun launched flyer plate. It appears that all EOS measurement techniques developed for light gas gun and explosively accelerated flyers, are applicable to railgun launched flyers.

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